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Implementation of Sequencing Batch Reactors for Municipal Treatment

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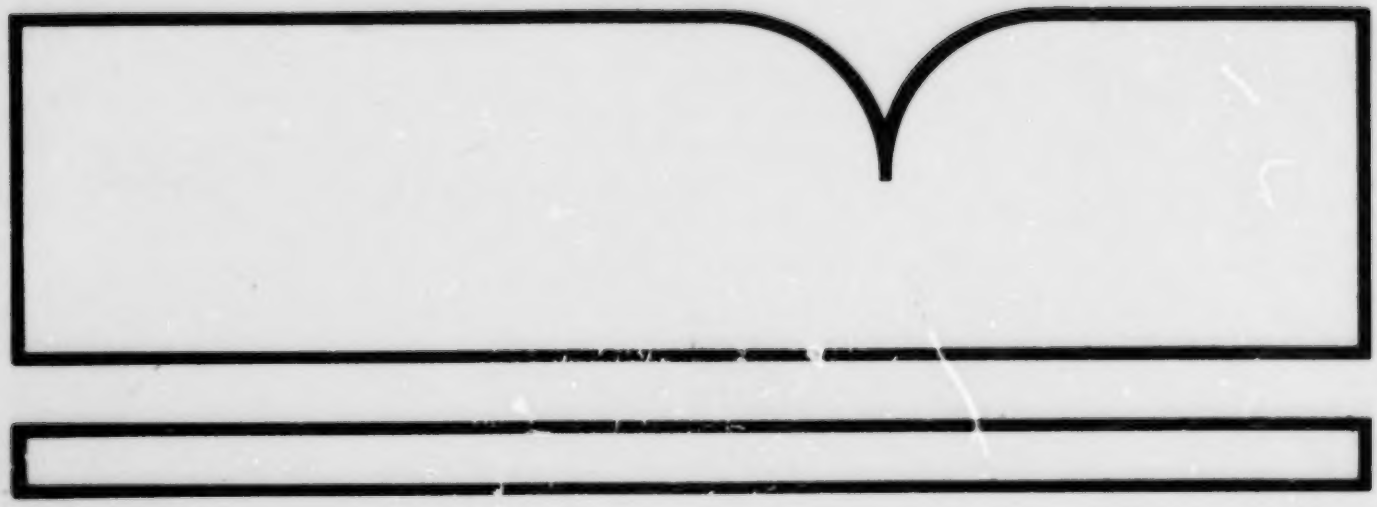

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IMPLEMENTATION OF SEQUENCING BATCH REACTORS FOR MUNICIPAL TREATMENT

by

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for

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16. ABSTRACT

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Batch treatment has inherent advantages over continuous processes in many applications.

Current research investigations on sequencing batch reactors concern controlling sludge settleability, nitrification, denitrification, and biological phosphorus removal.

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IMPLEMENTATION OF SEQUENCING BATCH REACTORS FOR MUNICIPAL WASTEWATER TREATMENT

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ABSTRACT

Sequencing batch reactor (SBR) technology is being implemented at various municipal sites in both the United States and abroad. Total life-cycle cost savings, ease of operation and reliability favor this technology at facilities sized up to 19,000 m^3 per day (5 mgd). Batch treatment has inherent advantages over continuous flow processes in many applications.

Current research investigations on SBR's concern controlling sludge settleability, nitrification-denitrification, and biological phosphorus removal.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

INTRODUCTION

This paper discusses progress of full-scale implementation and laboratory research on batch reactors. In the United States and several other countries sequencing batch reactors (SBR) are being designed and constructed for municipal facilities to meet a variety of effluent requirements. Studies are being conducted to seek operational patterns to achieve nitrification, denitrification, and biological phosphorus removal.

Historical technology is replete with examples of batch treatment of municipal wastewater. Sidwick and Murray (1) have outlined the evolution of batch processes into continuous flow processes in England. Early, in land treatment practices, it was recognized that intermittent irrigation of wastewater was necessary for reaeration of the soil to occur. In the year 1897, ways to conserve land were investigated. Vessels were constructed which contained various fine media (3mm) to try to duplicate soil surfaces. The first of these were operated as simple FILL and DRAW in accordance with intermittent land application experience. Later, a cyclic process was instituted which consisted of 2-hour FILL, 1-hour stand full and 5-hour drain. The cycle was repeated twice daily. Seventy-eight percent removal of organic matter was reported. The need to supply oxygen in the proper amount for active biological oxidation was the key finding of this early work. From this point on, two divergent developments led to continuous flow processes. One utilized larger media with greater void space so that wastewater splashing from surface to surface entrained oxygen from the surrounding air. This, of course, is the now familiar biological trickling filter. The other retained the concept of a flooded vessel containing media, but instituted continuous flow with suitable valving and supplied air by an external blower. This technology was the progenitor of the Hays Process (2) and

Imhoff's contact aerators (3). Conceptually, Imhoff discussed a variation of contact aerators which described rotating biological contactors before their actual invention.

The precursor to the various, now familiar, continuous flow activated sludge processes was actually a FILL and DRAW system operated as a batch process. Arden and Lockett (4) in 1914 were among the first to show the benefit of retaining substrate adapted organisms for efficient treatment. Working with 2.3 liter flasks containing Manchester, England, raw wastewater, they showed that the batch aeration period to achieve nitrification could be reduced from 5 weeks to 9 hours if the sludge that accumulated from each batch were retained in the flask after decanting the nitrified liquid. They coined the term "activated sludge" to describe the resultant biological mass. In later full-scale studies these same investigations (5) showed efficient treatment with an 8-hour batch cycle, as shown in Table 1.

TABLE 1. BATCH TREATMENT OF MANCHESTER WASTEWATER (modified from Ref. 5)
Year 1915

Analytical Results, mg/L			Operational Cycle, hours
	Raw	Effluent	
$KMnO_4$ (Oxygen Absorption)	124	18	Filling, 1 Aeration, 4
NH_4-N	37		Settlement, 2 Discharge, 1
Organic-N	12	1.9	
NO_2-N	--	1.4	There were 3 cycles each day and 20 percent activated sludge, by volume, was retained in the reactor after each cycle.
NO_3-N	--	14	

PRESENT DAY BATCH PROCESSES

Many present day industrial processes are batch processes; such as the dairy, steel, pharmaceutical and antibiotic, fine chemical, cosmetic, and paint industries.

In some instances, state regulatory agencies require that toxic wastes, such as cyanide, be detoxified by batch operation to insure the effluent can be monitored before discharge.

Most modern municipal treatment facilities utilize batch treatment in one guise or another, such as anaerobic digestion, aerobic digestion or intermittent discharge lagoons. Tchobanoglous (6) calls attention to the fact that the classical biological oxygen demand test (BOD) is a batch assay; however, the resultant data are used to design continuous flow processes.

Renewed interest in main stream batch treatment resulted from a mentorial article by Pasveer (7). He reported on the conversion of a continuously operated oxidation ditch; treating the waste from Sancta Maria Hospital, Noordwijkerhout, Holland, into a discontinuous discharge process with intermittent aeration. The operational change resulted in the control of a

filamentous activated sludge, improved clarification and yielded 90 percent denitrification.

Gronszy (8) has applied this concept of single tank treatment systems in Australia. Extended aeration processes are operated with continuous inflow but discontinuous discharge. The liquid level in the tank varies and various type decant devices are used. Aeration is provided in a cyclic manner to encourage nitrification and denitrification.

These two approaches provided a high degree of treatment due to the fact that they are both lightly loaded systems. Since the volume of the tank was large in comparison to the influent flow, the possibility of short circuiting influent to effluent was minor.

Irvine, the doyen of current investigations of batch process, has suggested a uniform terminology and united the batch concept with modern control strategies (9).

BATCH COMPARED WITH CONTINUOUS FLOW

Most simply stated, the conceptual difference between batch and continuous flow is that continuous flow processes have spacially related unit operations, whereas unit operations are timed sequentially in batch processes.

The generic batch process can have several modifications, such as single reactor, multiple reactors in series or parallel, and sequencing reactors; all with variable liquid levels. The most simple of these would be a variable volume single reactor as depicted in Figure 1, which would be suitable for a rural or small industrial situation where no flow occurs for part of the day. The figure shows the different time dependent modes that would occur in a complete cycle of a 1-tank reactor. The modes are labeled according to Irvine's (9) recommendation. The volume and cycle time are only illustrative. For any batch system, FILL and DRAW must occur in each cycle, but REACT, SETTLE, and IDLE could be eliminated depending on the objective of the treatment. Alternatively, other modes could be inserted by varying time and operational controls within a cycle. Systems of this nature have a great deal of flexibility. Table 2 compares batch and continuous flow processes. In several instances drastic differences can be noted and their impact on design, operation and effluent quality are apparent.

TABLE 2. COMPARISON OF BATCH AND CONTINUOUS PROCESSES

Parameter	Batch	Continuous
Concept	Time Sequence	Spacial Sequence
Inflow	Periodic	Continuous
Discharge	Periodic	Continuous
Organic Load	Cyclic	Even (by convention)
Hydraulic Load	Cyclic	Even (by convention)

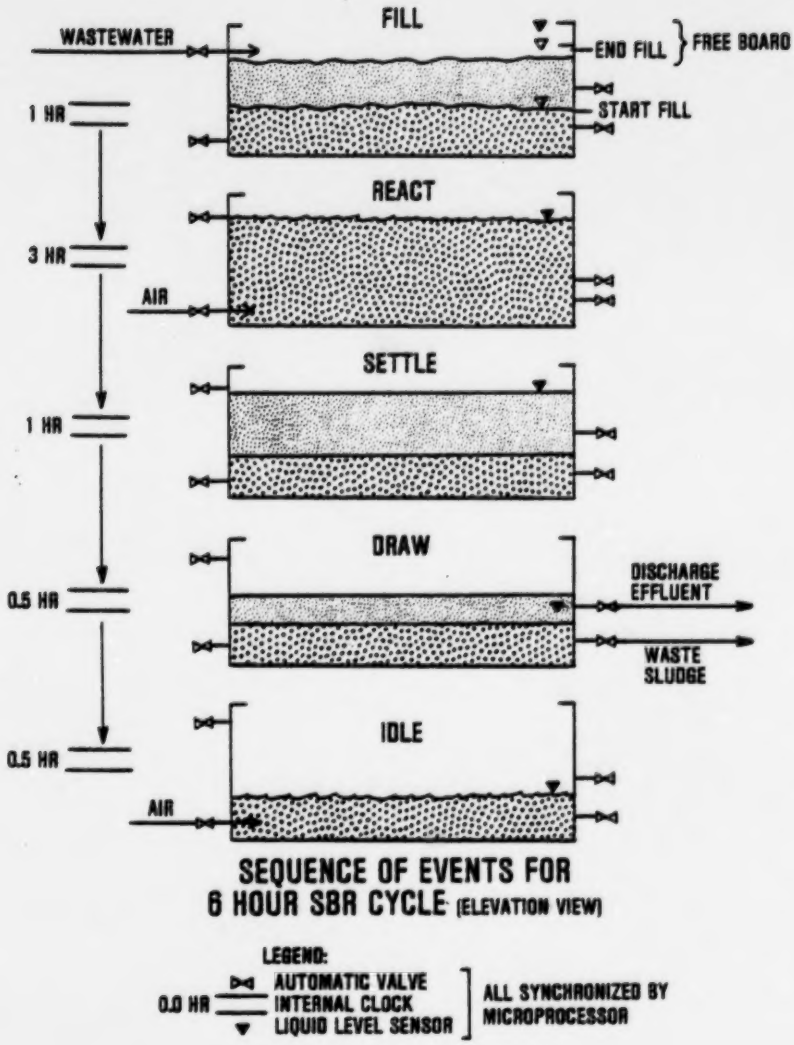

FIGURE 1. SEQUENCE OF EVENTS FOR 6 HR SBR CYCLE (ELEVATION VIEW)

TABLE 2. COMPARISON OF BATCH AND CONTINUOUS PROCESSES (cont'd)

Parameter	Batch	Continuous
Aeration	Intermittent	Continuous
Mixed Liquor	Always in Reactor, No Recycle	Recycles through Reactor and Clarifier
Clarification	Quiescent Hydraulics	Hydraulic Motion
Flow Pattern	Perfect Plug	Complete Mix or Approaching Plug
Equalization	Inherent	None
Flexibility	Considerable	Limited
Hydraulic Sizing	Variable	Uniform

Since the discharge is periodic, the possibility exists, within constraints, to hold effluent until some predetermined specific residual is obtained.

The cyclic organic and hydraulic loading coupled with inherent equalization allow control to be exerted over substrate tension in the reactor by suitably matching oxygen supply.

No recycle pumping is required, since the mixed liquor is always in the reactor, thereby saving on energy. All the active microbial mass is available and not shunted through an inactive period in a clarifier.

Liquid solids separation occurs under near ideal quiescent conditions. During the settling period there is no hydraulic motion due to inflow, outflow or recycle, as in continuous flow systems. The effluent exit piping must be sized larger than influent piping because flow accumulated over a long time span is discharged in a much shorter time span.

In situations where the influent flow is continuous, two or more tanks operated in sequence would be needed to treat the flow. A two-tank sequencing batch reactor (SBR) schematic is shown in Figure 2. As one tank progresses from the FILL to the REACT mode, flow is switched to the second tank, which starts a new cycle in the Fill mode. When capital costs and operational controls are considered, Irvine and Richter (10) indicate a three-tank system is near optimum for flows above 3,785 m^3d (1 mgd).

Because sequencing batch reactor technology is new to both designers and treatment plant operators, the major applications are currently for facilities of 19,000 m^3 per day (5 mgd), or less. This lack of experience on large size facilities is no barrier to implementation. Between the years 1983 and 2000, it is anticipated that 3,000 municipal facilities with design flows less than 7,500 m^3 per day (2 mgd) will need to be constructed in the United States. About 2.5 billion dollars will be expended on these sized treatment plants.

OPERATIONAL CONSIDERATIONS

Since the majority of the SBR's being constructed are of small size a recent discussion of energy utilization at municipal facilities by Smith is of interest (11). This discussion shows that in the 3,785 m^3 per day (1 mgd) size range energy consumption is only 8.1 percent of the operating cost and labor accounts for 68.2 percent of the cost. Therefore, the SBR process with automated valving, and a process controller which eliminates major labor times, is a logical selection at small facilities. In Australia, where modifications of the SBR have been employed for several years, it is common to have one operator manage four facilities in a several hundred square kilometer area. Also, designers are beginning to recognize the attributes of the SBR in many situations. Barth has noted flexibility, equalization, quiescent settling, elimination of recycle pump, and process reliability, as criteria that direct selection of batch systems for many installations (12).

Bathija has described various SBR tank designs and operational schemes (13). Racetrack, rectangular (length to width ~ 4:1), and circular SBR facilities have been constructed. Recommended side-water depth is 3 to 4.5 m (10 to 15 ft). If both aeration and mixing are independently necessary, a jet type aeration device is preferred. If separate mixing only is not a process requirement any non-clogging or mechanical aeration system can be specified.

Bathija also suggests SBR solutions to two common problem areas in municipal treatment; reduced hydraulic flow during the early design life of a facility, and increased hydraulic flow during storm events. During the early design life period of reduced flow, liquid level sensors can be set at a fraction of tank capacity. In this way, the length of treatment cycles is the same as design, and power is not wasted by over-aeration during an excessively long cycle time. There are several approaches to manage increased hydraulic flow during storm flows. If level sensors are left in their usual position, increased flows will cause the number of cycles per day to increase. If this should cause a reduction in efficiency the level sensors could be raised, within free-board limits, to keep the cycle time near design requirements. Either of these two management approaches could be coupled with modification of the time periods within a cycle. For instance, the time devoted to IDLE could be eliminated and that time period shifted to increase REACT time, yet not alter the overall design cycle time.

The SBR process has an outstanding reliability feature during increased hydraulic flows. The mixed liquor solids always remain in the reactor and cannot be washed out by hydraulic surges. Also, there is no recycle flow from a separate clarifier and, therefore, an SBR process does not rely on return sludge capability to maintain an adequate level of mixed liquor solids during increased hydraulic flow.

EQUIPMENT SELECTION

Because the SBR process is rather new, several types of instrumentation are being pursued. Some designs are employing photoelectric level sensors, others use float level switches for controlling reactor liquid level. Automated valves for control of reactor influent and effluent range from pneumatic devices to motorized gate valves.

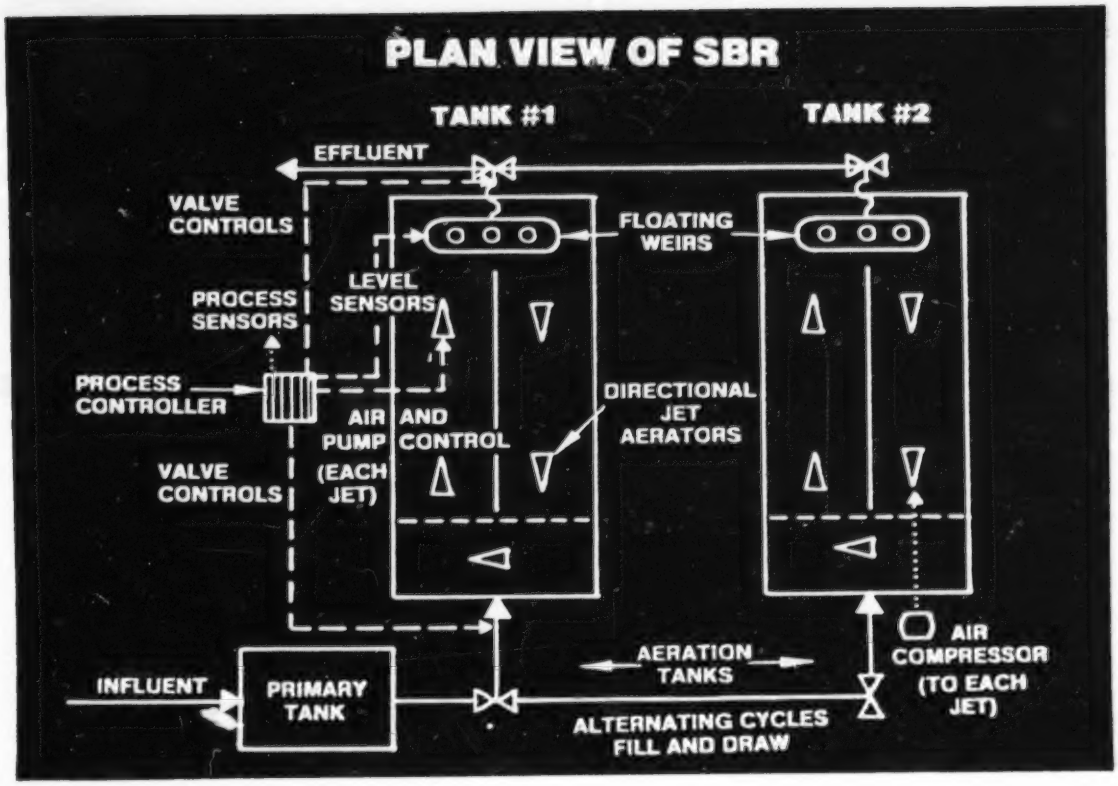

FIGURE 2. SEQUENCING BATCH REACTORS

Effluent discharge devices can be submerged standpipes, tipping weirs, float supported collector pipes, or submerged pumps.

In all but the smallest systems, commercial process controllers are used to time and control the process sequence. In systems under 20 m^3/day (5000 gpd) simple time clock and electrical solenoid valves would be recommended.

INDUSTRIAL APPLICATION

Dairy Waste

The Springfield Creamery in Springfield, Oregon, produces a waste that has a large concentration of soluble oxygen demand, intermittent flow, and extreme pH fluctuation. Flow is 40 m^3/day (10,000 gpd). An adjoining meat packing plant has a large concentration of suspended oxygen demand, intermittent flow, and stable buffered pH of about 7. Flow is 8 m^3 per day (2000 gpd).

Upon learning of the inherent equalization of an SBR process, ease of operation, wide flexibility of treatment options, and simple design considerations, the two companies plan to mix these waste streams for combined treatment. The SBR will be an earthen basin with dimensions of 7.5 m x 4.5 m x 2.4 m (25 ft x 15 ft x 8 ft). Aeration will be provided by a submerged pump with an air blower exhaust line tapped into the intake side of the pump. Since the flows are intermittent, a single tank system will be adequate.

Chemical Waste

Due to the facts that SBR's can be operated to produce a defined residual concentration of a pollutant with no possibility of short circuiting, and that quiescent settling produces very clear effluent, the process has been selected to treat a combination of landfill leachate and chemical manufacturing wastes in Niagara, New York.

The plant wastes are generated from the industrial operations and the leachate is collected from a remote landfill area via collection underdrains and hauled by truck to the plant site. Both type wastes contain several hazardous organic pollutants. Daily design flow is 600 m^3.

The exsting treatment at the industrial site consits of a storage tank, neutralization tank and carbon absorption columns; with discharge of the column effluent to the city sewer. Operation has shown that with this physical/chemical process, excessive soluble organic matter quickly saturates the absorption capacity of the carbon columns requiring frequent thermal regeneration of the carbon. Upgrading construction will add two biological SBR's, to reduce the soluble organics, and provision for adding ammonia and phosphate to serve as nutrients for the SBR biomass.

Many of the organic components of the mixed waste have slow rates of biodegradation. To insure efficient degradation, the SBR contents will be monitored for total organic carbon during REACT until a predetermined concentration is achieved. Thus, the SBR will decrease the organic loading to the carbon columns and efficient settling will not overly burden the columns with suspended solids. Waste activated sludge from the SBR's will be incinerated to destroy any sorbed hazardous pollutants on the sludge surface.

Pilot SBR operation at a scale of 50 m^3/day (13,000 gpd) has shown a 90 percent reduction of soluble organic carbon from the influent mixed waste. It is therefore anticipated that the useful life of the carbon, before regeneration is necessary, will be increased by almost a factor of 10. Figure 3 is a schematic of the full-scale process as it will exist in 1985.

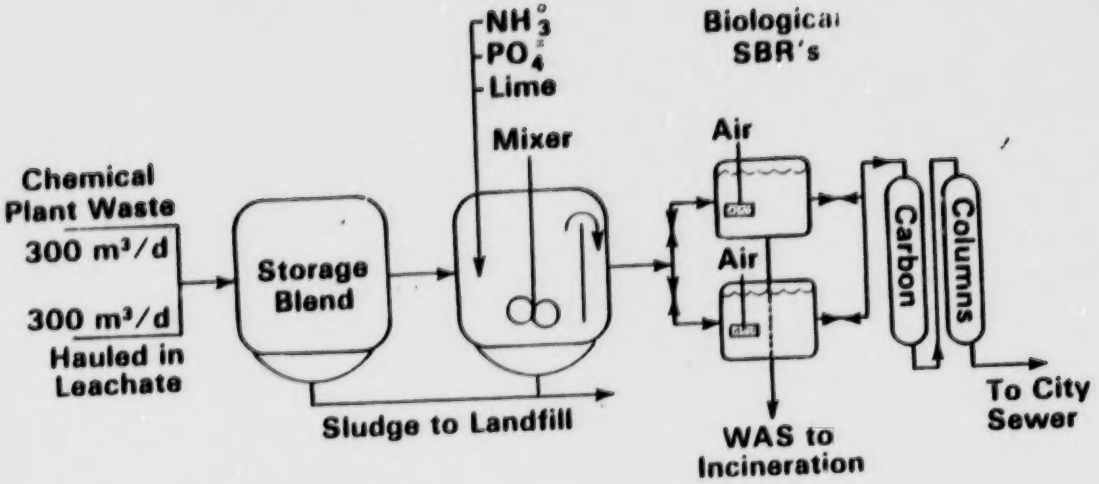

FIGURE 3. SBR-CARBON ADSORPTION FOR INDUSTRIAL WASTE

MUNICIPAL APPLICATION

Recognition of the virtues of SBR's and the emergence of reliable process control hardware lead to the USEPA to fund a development project, conducted by The University of Notre Dame, to re-evaluate municipal batch treatment. The project involved the conversion of the existing 1,500 m^3/day (0.4 mgd) Culver, Indiana, continuous flow activated sludge facility into a two-tank SBR (14). The new flow scheme is the same as shown in Figure 2.

Primary effluent is directed to each tank on an alternate basis as dictated by liquid level sensors in each tank. Pneumatic compression pinch valves control tank switching. Aeration and mixing are provided by directional jet aerators. Effluent is decanted during DRAW by submersible pumps attached to flotation devices which are swivel mounted to allow changes in elevation of the pump suction.. All of these functions are programmed into a process controller which operates and monitors all aspects of treatment.

The controller programs for both Tank-1 and Tank-2 operate independently in order to have greater mode flexibility within a cycle. However, a main program monitors the Tank-1 and Tank-2 programs on a time-sharing basis to insure correct sequencing.

The initial evaluation at the Culver facility used an anoxic period for part of the FILL mode and this was programmed into the controller as FILL-1 and FILL-2. During FILL-1, only the mixing action of the jet pumps was activated. During FILL-2, the jet pumps mixed and aearated simultaneously. A typical cycle for the two tanks was as follows:

	Hours in Mode					
	Fill-1	Fill-2	React	Settle	Draw	Idle
Tank-1	1.1	1.8	0.8	0.8	0.7	0.8
Tank-2	1.2	1.9	0.6	0.8	0.6	0.9

The difference in times between the modes of the two tanks is due to flow variation, since the system is controlled by liquid level sensors. At the design flow of 1,500 m^3/d (0.4 mgd) each cycle is completed in 6 hours and both tanks complete 4 cycles each day.

The process conditions at Culver were:

F/M	0.2 kg BOD_5/kg MLSS/d
SRT	20 days
MLSS	2,200 mg/L (70 percent volatile)
SVI	110 ml/g

One year of data and operational experience has been documented for BOD_5 and SS control. Table 3 provides monthly average wastewater and SBR effluent constituents for 8 months of 1980. The City of Culver has an effluent phosphorus limitation of 1 mg/L. To achieve removal of phosphorus, ferric chloride is dosed directly into the primary effluent channel leading to Tank-1 and Tank-2.

Very high efficiency for BOD_5, SS and TP is achieved at Culver with the SBR process. Nitrate nitrogen of about 2 to 5 mg/l is usually present in the

Culver raw wastewater due to run-off from fertilized farm land infiltrating sections of the collection system. Table 3 shows that this influent nitrate is denitrified during the anoxic FILL-1 mode of the SBR.

TABLE 3. CONSTITUENTS OF CULVER, INDIANA PROCESS STREAMS
MAY - DECEMBER, 1980

Location	Milligrams per Liter				
	BOD_5	SS	TP	NH_4-N	Oxidized Nitrogen
Raw Wastewater	173	136	6.3	20	2.8
Primary Effluent	132	81	5.2	19	2.6
SBR Tank-1	8	7	0.4	19	0.4
SBR Tank-2	9	9	0.4	18	0.4
Overall Removal, Percent	95	94	94	5	86

Process conditions to achieve nitrification and denitrification were implemented during a second study period. The anoxic period for FILL-1 was reduced to provide a longer period of dissolved oxygen supply for nitrification. The efficiency of the SBR process during the last five months of 1981 is given in Table 4.

Nitrification and denitrification occurred almost simultaneously, as evidenced by the fact that neither ammonium or nitrate nitrogen reach high concentrations in the reactors. Apparently as ammonium nitrogen is transformed to nitrate, during the low load period at the start of FILL, there is subsequent denitrification due to the high mixed liquor concentration and differential D.O. content of the reactor. When mixed liquor is pumped through the aerated jet nozzle a high D.O., suitable for nitrification is present; then as the mixed liquor circulates as a bulk liquid localized low D.O. conditions can occur.

Once nitrification is established in the Culver SBR, ammonium nitrogen concentration in the reactor can never reach influent levels due to the dilution of influent by the residual reactor contents left after IDLE, and the biological transformation to nitrate. Accordingly, the nitrate concentration cannot reach high levels, and even a low kinetic rate for denitrification would yield fairly efficient nitrogen removal.

TABLE 4. EFFICIENCY OF CULVER SBR FOR NITRIFICATION AND DENITRIFICATION AUGUST - DECEMBER, 1981

	Milligrams per Liter				
Location	BOD_5	SS	TP	NH_4-N	Oxidized Nitrogen
Raw Wastewater	158	150	7	20	2
Primary Effluent	110	82	5	18	2
SBR Tank-1	10	5	0.7	1	1
SBR Tank-2	9	6	0.8	1	1
Overall Removal, Percent	94	96	89	95	-

LABORATORY RESEARCH ON SBR's

Control of Sludge Bulking

Working with 4 L SBR's, fed a soluble synthetic wastewater, Chiesa has correlated sludge volume index (SVI) with aeration time during the FILL period (15). He used the following strategies to manage the substrate tension in the SBR's:

Control Strategy	Unaerated/Unmixed FILL, hr	Aerated FILL, hr	Aerated REACT, hr	SETTLE, DRAW and IDLE, hr
A	2.00	0.00	4	2
B	1.75	0.25	4	2
C	1.50	0.50	4	2
D	1.25	0.75	4	2
E	1.00	1.00	4	2
F	0.00	2.00	4	2

Very spectacular results were obtained as shown in Figure 4. To confirm this observation, an SBR operated under control strategy F, with an SVI of 600 mL/g, was switched to strategy A; and in 15 days the SVI decreased to 100 mL/g.

These researchers explain these observations on the basis of competitive growth of one group of organisms in opposition to other groups. They postulate that strategy A, where substrate tension surrounding the organisms reaches a high level during FILL, and subsequent oxidation of organics and endogenous metabolism during REACT, which places the organisms in periodic starvation, selectively encourages the growth of floc forming organisms.

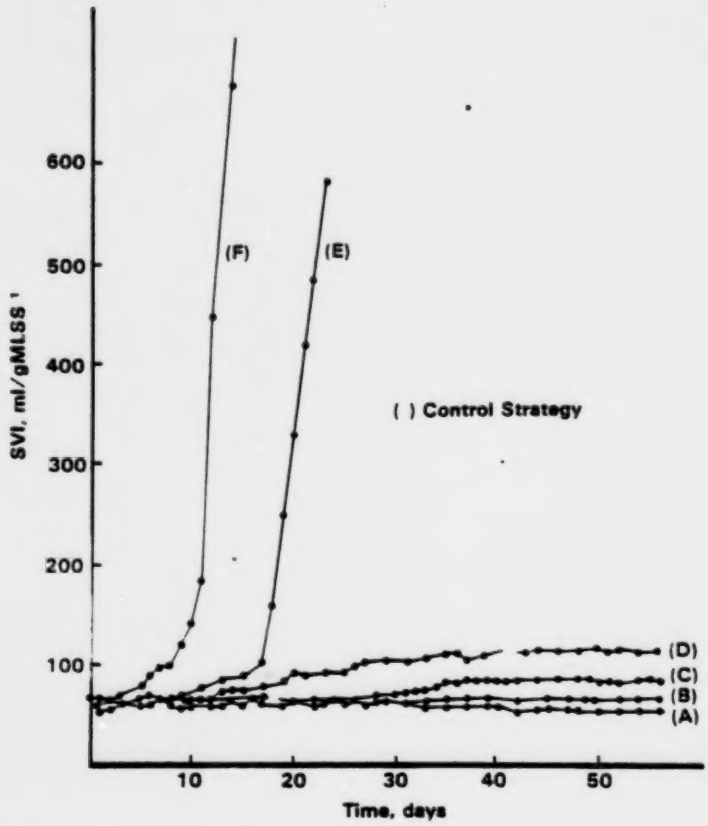

FIGURE 4. SVI AS A FUNCTION OF CONTROL STRATEGY
(FROM REF. 7)

Filamentous organisms survive best when the substrate tension is constantly maintained at a low level such as in strategy F.

The sludge developed under strategy A had a greater specific oxygen uptake rate than did the F strategy sludge; and the A sludge was much more efficient in substrate removal rate than the F sludge.

The authors point out the great flexibility of the SBR process to control substrate tension at any desired level. It can be noted in the above strategies that A would be equivalent to contact stabilization and F would be similar to a completely mixed activated sludge process.

Biological Phosphorus Removal in an SBR

Discussions at the June 1982 "Workshop on Biological Phosphorus Removal" showed a similar process feature for three proprietary phosphorus removal systems (16). This feature is shown conceptually in Figure 5. When activated sludge mixed liquor is subjected to an anaerobic or anoxic environment* with influent organic substrate, there is coincident leaching of phosphorus from the cellular material and sorbtion of organic matter. When environmental conditions are changed to an aerobic state, phosphorus is removed from solution and organics are oxidized.

The following several theories have been proposed to explain this finding:

a) Anaerobic-aerobic staging can result in selection of a biological population that is capable of storing polyphosphates. The actual mechanism for storage and release and the basis of population selection is not known.

b) The regulation of the adenosine diphosphate ratio to adenosine triphosphate (ADP/ATP) controlled by the reversible enzyme polyphosphate kinase has been suggested as a mechanistic factor. When cells are placed in a "stress condition" such as lack of oxygen during an anoxic period, large amounts of polyphosphates are then stored in the cells when subsequent aerobic conditions are provided and cellular growth is rapid.

c) Another theory suggests that polyphosphate storage ability of certain bacteria allow them to compete and survive in an alternating anoxic-aerobic environment. The energy derived by hydrolysis of polyphosphate (ATP) may be used directly for transport of substrate across the cell membrane in the anoxic condition.

d) Polyhydroxy butric acid (PHB) has also been suggested as an important consideration. It has been noted that PHB is formed during anoxic conditions, and organisms such as Acinetobacter can accumulate both PHB and phosphates.

These various mechanistic theories seem to show that some type conditioning occurs during the anoxic period; whether enzymatic hydrolysis, uptake of a metabolite or environmental stress that confers a competitive advantage to certain phosphate storing organisms when conditions are switched to an aerobic state.

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*The term anaerobic refers to environments which have no measurable concentrations of either oxygen or oxidized nitrogen. Often times appreciable concentrations of carbonaceous materials must be present to maintain this condition. Anoxic refers to environments which have no dissolved oxygen but have oxidized nitrogen present. However, these two terms were used almost interchangeably in the workshop discussions (16).

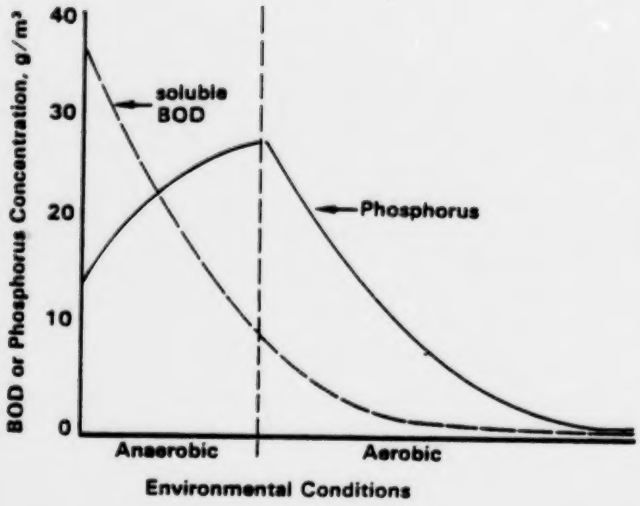

FIGURE 5. BIOLOGICAL PHOSPHORUS AND BOD_5 REMOVAL DUE TO ANAEROBIC-AEROBIC CONTACTING (REF. 17)

The PhoStrip process* utilizes this anaerobic or anoxic leaching to remove phosphorus from a portion of mixed liquor in a side stream stripper tank. Both the A/O** and Bardenpho*** processes remove phosphorus by baffling the biological reactor to maintain the mainstream flow environmental conditions suitable for each process' operation.

Also, all three processes were reported to be subject to inhibition of phosphorus leaching during the anaerobic or anoxic phase if nitrate ion was present. If nitrate was present, provision for denitrification before phosphorus leaching had to be provided.

All of these applications for phosphorus removal are for continuous flow systems. The Municipal Environmental Research Laboratory is employing an SBR for studying biological phosphorus removal because the batch approach should allow close control of environmental conditions. A schematic of the 4 L bench-scale reactor used for these studies is shown in Figure 6. A vast number of operational schemes can be employed using a microprocessor controlled SBR. In order to achieve the release and uptake of phosphorus noted in Figure 5, the following cycle scheme was employed:

Cycle Event	Time	Purpose	Note
FILL+	1 hr	Add substrate	No aeration
STRESS	4.5 hr	Cause phosphorus leaching and denitrification	Mixer on No aeration (Time overlaps with FILL time)
AERATE	1 hr	Cause phosphorus uptake, and oxidize organics	Aeration
WASTE SLUDGE	4 sec	Remove phosphorus from reactor, and control SRT	Aeration
SETTLE	15 min	Form clear supernatant	No aeration
DRAW	5 min	Discharge effluent	No aeration
IDLE	10 min	Adjustment of cycle length	No aeration

*Biospherics, Inc., 4928 Wyaconda Rd., Rockville, MD 20852
**Air Products, Inc., Box 538, Allentown, PA 18105
***EIMCO-PMD, 3839 S. West Temple, Salt Lake City, UT 84115
+Primary effluent from Cincinnati's Muddy Creek treatment plant used.

The total cycle time was 6 hours and therefore the SBR emptied and filled 4 times each day.

The results achieved are shown in Figure 7. During FILL the phosphorus concentration in the reactor is affected by the phosphorus content at the end of the last cycle event (either DRAW or IDLE), the concentration in the feed entering the reactor and the leaching of phosphorus from mixed liquor solids. In the case depicted, the residual phosphorus in the SBR was diluted as primary effluent, with a smaller concentration entered, and a gradual increase to 33 g/m^3 occurred as mixed liquor cellular leaching occurred. During the STRESS period a plateau concentration existed, until aeration was commenced, and cellular uptake reduced the concentration to 2.5 g/m^3. Effluent filtered orthophosphorus concentrations approaching 0.0 g/m^3 have occasionally been noted.

Nitrate nitrogen remained at about 1 g/m^3 during STRESS due to the occurrence of denitrification. A dramatic increase of nitrate formation occurs once aeration is commenced and dissolved oxygen increases.

The SBR was operated under this regime for 30 days (120 cycles) using the Muddy Creek primary effluent. SBR effluent residual orthophosphorus was routinely between 2.5 and 0.5 g/m^3. Influent total phosphorus varied between 20 g/m^3 and 15 g/m^3, with orthophosphorus between 20 g/m^3 and 6 g/m^3. Muddy Creek wastewater is primarily domestic waste.

The process management to control biological phosphorus removal can be illustrated by referring to Figure 7. During FILL and STRESS, conditions have to be provided to cause denitrification of any nitrate and insure that leaching from the cellular mass occurs. STRESS periods ranging from 2 to 6 hours have been studied. Three hours appears to be the minimum time that can be employed. An aeration period of at least 1 hour is necessary to reincorporate the leached phosphorus and oxidize organics. Aeration times greater than this lead to less efficiency due to lysis of cells during endogenous respiration. Wasting of sludge from the SBR must be done when the biological solids have the highest content of phosphorus. This would be at the end of AERATE, which yields a dilute waste activated sludge of the same solids content as the mixed liquor. Or, wasting can be done near the end of SETTLE, which provides a thickened waste activated sludge. Caution is required here in case low dissolved oxygen in the sludge blanket causes leaching of phosphorus. Thus, overall efficiency of biological phosphorus removal dictates that SETTLE time be as short as possible, yet provide good solids separation. A minimum of 15 minutes and a maximum of 30 minutes has been satisfactory.

Time devoted to DRAW is not critical to biological phosphorus uptake directly. Mainly, on full-scale SBR's this time period would be related to effluent weir design to insure proper hydraulics within the reactor, and hydraulics of discharge appurtenances. Provision for an IDLE period is optional in SBR operation for biological phosphorus removal. A short IDLE period, either quiescent or aerated would have no impact on overall efficiency. IDLE is simply a convenience of adjusting cycles between reactors if two SBR's are operated alternately. The same SBR process cycle described above was employed with wastewater from Cincinnati's Little Miami facility. This waste contains a major fraction of wastes from a variety of industrial processes. Consistent biological phosphorus removal could not be achieved. Over a three month period variations to FILL, STRESS, and AERATE were attempted

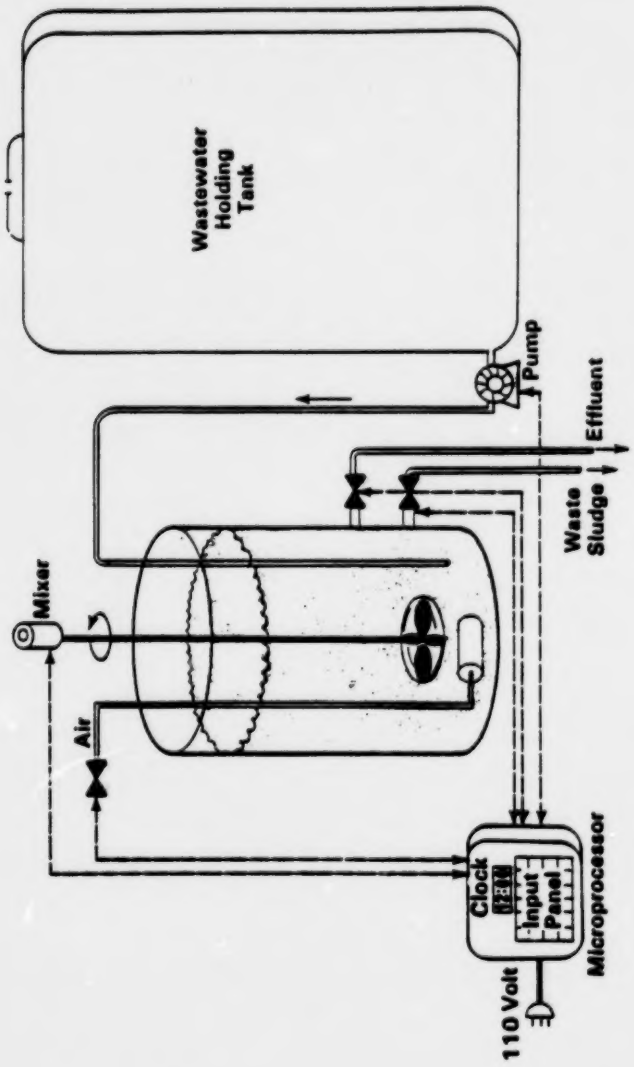

FIGURE 6. 4 L BENCH-SCALE SBR

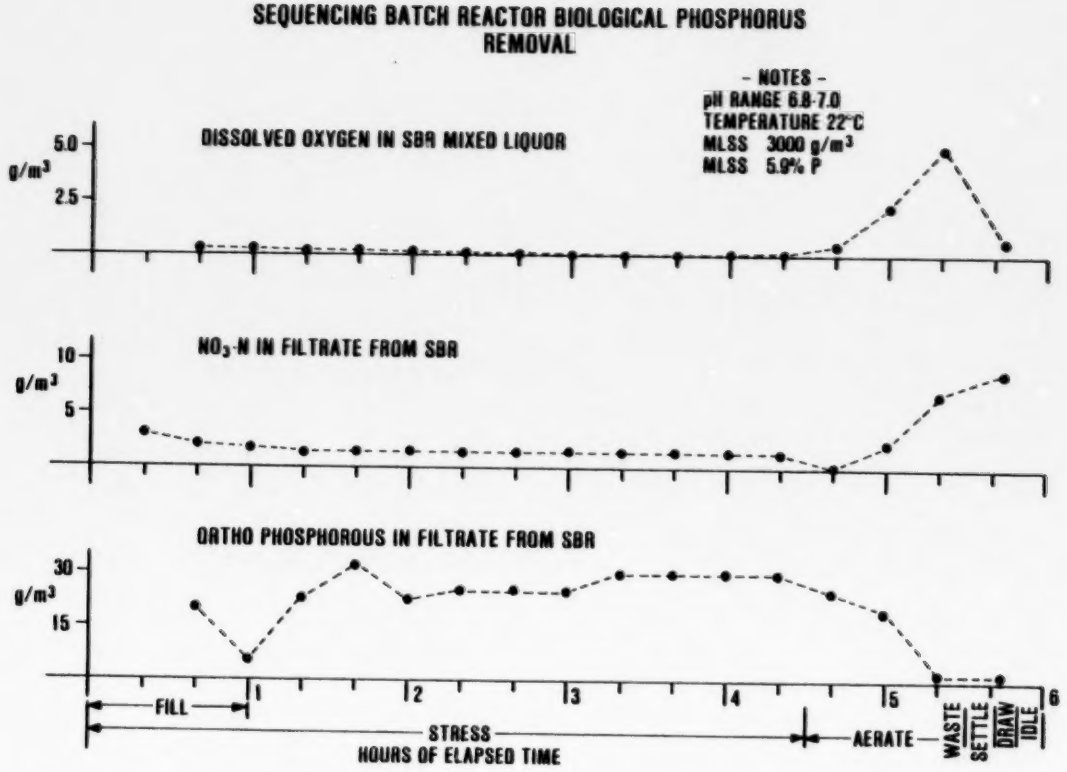

Figure 7. SBR BIOLOGICAL PHOSPHORUS REMOVAL

without success. Efficient removal with residual orthophosphorus values of 0.5 to 1.0 g/m^3, would be noted for several days; then deterioration of efficiency would occur.

These SBR studies, on two wastewaters, have not as yet revealed the controlling parameters to insure consistent, highly reliable biological phosphorus removal. This same conclusion was noted for the three continuous flow biological phosphorus removal processes dicussed at the Annapolis workshop (16).

Presently it would be recommended that any facility plan for biological phopsphorus removal be guided by pilot plant studies prior to final selection. Additionally, in those cases where a high reliability of phosphorus removal is necessary, it would be recommended that a chemical addition system be installed as backup equipment.

REFERENCES

1. Sidwick, J. M., and Murray, J. E., "A Brief History of Sewage Treatment (Part 1)." Effluent and Water Treatment Jour., Feb., 65 (1976).

2. Hurley, J., "Contact Aeration for Sewage Treatment." The Surveyor, 10, 183 (1943).

3. Imhoff, K., and Fair, G. M., Sewage Treatment. John Wiley and Sons, Inc., New York, N.Y. (1940).

4. Ardern, E., and Lockett, W. T., "Experiments on the Oxidation of Sewage without the Aid of Filters." Jour. Soc. Chemical Ind., 33, 523 (1914).

5. Ardern, E., and Lockett, W. T., "The Oxidation of Sewage without the Aid of Filters. Part III." Jour. Soc. Chemical Ind., 34, 937 (1915).

6. Tchobanoglous, G., Wastewater Engineering: Treatment Disposal Reuse. McGraw-Hill, Inc., New York, N.Y. (1979).

7. Pasveer, A., "A Case of Filamentous Activated Sludge." Jour. Water Poll. Control Fed., 41, 1340 (1969).

8. Goronszy, M. C., "Intermittent Operation of the Extended Aeration Process for Small Systems." Jour. Water Poll. Control Fed., 51, 274 (1979).

9. Irvine, R. L., Sequencing Batch Reactors - An Overview." Jour. Water Poll. Control Fed., 51, 235 (1979).

10. Irvine, R. L., and Richter, R. O., "Computer Simulation and Design of Sequencing Batch Biological Reactors." 31st Industrial Waste Conference, Purdue University (1976).

11. Smith, J. M., "Energy Recovery and Conservation for Low-Cost Systems." Workshop on Low-Cost Treatment. Clemson University, April 1983.

12. Barth, E. F. (III)., "Sequencing Batch Reactors: Doing More with Less," Federal Water Quality Association Newslette, Vol. 10, No. 1, October 1982.

13. Bathija, P. R., "The Jet Age in Sequencing Batch Reactors," Seminar on Emerging Technologies, Boston, Massachusetts, December 15, 1981.

14. Irvine, R. L., Ketchum, L. H., Breyfogle, R., and Barth, E. F., "Municipal Application of Sequencing Batch Treatment." Jour. Water Poll. Control Fed., 55, 484 (1983).

15. Chiesa, S. C., and Irvine, R. L., "Growth and Control of Filamentous Microbes in Activated Sludge." 55th Annual Conference Water Pollution Control Federation, St. Louis, Missouri, October 1982.

16. Workshop on Biological Phosphorus Removal in Municipal Wastewater Treatment. Summary report, Annapolis, Maryland, June 1982.

17. Hong, S., et al., "A Biological Wastewater Treatment System for Nutrient Removal." Air Products and Chemicals, Inc., June 22, 1982.